

INTERPRETATION OF VARYING CHARACTERISTICS OF THERMOPOWERS OF SILVER – SAMPLES AT LOW TEMPERATURE

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ABSTRACT

Thermopowers of Silver samples with varying amount of twisting show-varying characteristics in respect of temperature variation and magnitude at low temperature, as reported in the literature. These characteristics are interpreted in terms of dominating role of residual thermal resistivity caused by twisting. The interpretation of anomalous behaviors of Thermopowers of simple metals at low temperature in terms of phonon drag effect is also tested in these cases and it is not found to be suitable.

KEYWORDS: Thermopowers, Twisting Show-Varying Characteristics

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INTRODUCTION

Varying behavior of thermo powers of different samples of Silver at low temperature, reported in the literature¹⁻⁵ is shown by different curves in fig.1. Different curves represent the characteristics of thermo powers of different samples, of Ag. Values of RR [$RR = \frac{\rho_{300}}{\rho_{4.2}}$]; ρ_{300} and $\rho_{4.2}$, are the electrical resistivities of a samples at T= 300K and T= 4.2K, respectively. As the amount of twisting of a sample is increased, the residual resistivity increases and behavior of the thermopower changes. For a low amount of twisting, the peak appears in thermopower. As the amount of twisting increases, the height of the peak increases and the temperature at which the peak occurs, shifts towards the higher value of T. However, as the amount of twisting increases beyond a certain value, the peak disappears and the curve begins to take the shape of a straight line. The magnitude of thermopower of Ag-sample at a temperature varies with the amount of twisting.

Conventionally, anomalies such as nonlinearity in temperature dependence and larger magnitude than the theoretical value, of thermopower of a simple metal, at low temperature are interpreted in terms of phonon - drag component of the thermo power. In phonon - drag effect in thermopower, diffusing electrons are dragged by the stream of phonons. In this process, the diffusion rate of electrons is enhanced which results in the enhancement of diffusion thermopower (S_e). The enhanced amount of thermopower is termed as phonon - drag component⁶⁻⁷, of thermo power (S_g). Theoretically⁶⁻⁷, S_e varies as T and $S_g \propto T^3$. At low temperature, thermo power (S) of a simple metal is written as,

$$\begin{aligned} S &= S_e + S_g \\ &= AT + BT^3 \end{aligned} \quad (1)$$

$$\text{Where } A = \frac{\pi^2 \kappa_0^2}{3\mu_0 e} \text{ and } B = \frac{78\kappa_0}{e\theta^3} \alpha$$

$$[\alpha < 1]$$

μ_0 is the Fermi energy of electrons at $T=0$

κ_0 = Boltzman constant, e is the electronic charge. And θ is the Debye temperature.

The first term of eqn. (1) in R. H. S. is the electron- contribution and second one stands for the phonon- drag contribution⁶⁻⁷. Eqn. (1) shows that the nonlinearity in temperature dependence and larger value of S than S_e are due to the presence of term BT^3 . We calculate the value of S_e and S_g using the expressions.

$$S_e = \frac{\pi^2 \kappa_0^2}{3\mu_0 e} T \text{ and } S_g = \frac{78\kappa_0}{e\theta^3} T^3 \text{ with } \mu_0 = 5.5 \text{ eV. and } \theta = 220K \text{ for Ag.}$$

These calculated values are shown in Table-1. Values of $S = S_e + S_g$ is much greater than the observed values at any of temperatures under test we have chosen three temperatures at which peaks in S occur [C.f. figure 1]. In the above calculation we have taken $\alpha=1$. Now we calculate α from eqn.

$$S(\text{peak}) - S(\text{theoretical}) = \frac{78\kappa_0}{e\theta^3} T^3 \alpha \quad (2)$$

These values of α are shown in Table (2). Values of RR are also given. Table -2 shows that values of α increases with increasing amount of residual resistivity, which is against the phonon drag contention as according to the contention value of α should decrease with increasing value of the residual resistivity⁶.

The mechanism of phonon - drag effect in the thermo power of metals, which leads⁶ to the same nature (sign), of S_e and S_g . Therefore, eqn. (1) fails to interpret the occurrence of a peak in S .

These results don't support the suitability of phonon drag interpretation, discussed above. In this communication, we try to interpret the previously mentioned characteristic of Thermopowers of Ag samples in terms of residual thermal resistivity assuming the validity of Weidman- Franz law using Nordheim- Gorter rule (N.G. rule) of Thermopowers.

1 INTERPRETATION IN TERMS OF RESIDUAL RESISTIVITY

According to N.G. rule of thermopower, thermopower of a metal is written as

$$S = \frac{S_r W_r + S_i W_i}{W_r + W_i} \quad (3)$$

Where W_r and W_i are the residual and ideal thermal resistivities respectively, W_i is caused by the scattering of electrons by phonons and W_r is due to scattering of electrons by impurities and lattice defects. S_r is the thermopower associated with impurities and lattice defects and S_i is the characteristic thermopower of the metal. At low temperature thermal conductivity of a metal is represented as

$$\kappa = \frac{T}{\beta + bT^3} \quad (4)$$

Where β and b are constants for a sample of a metal. Eqn. (4) leads to

$$W_r = \beta/T \quad \text{and} \quad W_i = bT^2 \quad (4a)$$

$$S_r = a_r T \quad \text{and} \quad S_i = a_i T \quad (4b)$$

Where a_r and a_i are constants. The linear temperature dependence of S_r or S_i is followed from the free electron approximation in metals.

From eqns. (3), (4a) & (4b), we have

$$S = \frac{a_r \beta T}{\beta + bT^3} + \frac{a_i bT^4}{\beta + bT^3} \quad (5)$$

$$= S_1 + S_2 \quad (5a)$$

$$\text{Where } S_1 = \frac{a_r \beta T}{\beta + bT^3} \quad \& \quad S_2 = \frac{a_i bT^4}{\beta + bT^3} \quad (5b)$$

Under the condition $\beta \gg bT^3$, eqn. (5) may be reduced to

$$S = a_r T + \frac{a_i bT^4}{\beta} \quad (6)$$

$$S = S_r + \frac{S_i bT^3}{\beta} \quad (6a)$$

$$S \approx S_r = a_r T \quad (6b)$$

Eqn. (6), shows the nonlinear temperature dependence of S and (6b), suggests S to be the linear function of T . It implies that, for low value of β , ie low value of residual resistivity, non linearity in temperature variation of S appears and S becomes linear, when the value of β becomes large. For high value of β , S_r alone remains significant, and the magnitude and sign of S are determined by that of S_r .

For the peak value of S_1 , the condition,

$$\beta = 2bT^3 \quad (7)$$

is satisfied [c.f. eqn. (5b)]

The eqn. (7) leads to

$$T = \left[\frac{\beta}{2b} \right]^{1/3} = T_1^* \quad (8)$$

T_1^* is the temperature at which a peak of S occurs. Its value increases with the the value of β i.e, $T_1^* \propto [\beta]^{1/3}$.

It suggests that values of T_1^* shifts towards the higher value of T as value of β increases.

Peak value of S_1 is is given by

$$[S_1]_{peak} = \frac{a_r \beta T_1^*}{\beta + b T_1^{*3}} = \frac{2}{3} a_r \left[\frac{\beta}{2b} \right]^{1/3} \quad (9a)$$

$$= \frac{2}{3} a_r T_1^* \quad (9b)$$

This eqn. suggests that peak value of S_1 increases with increasing amount of β . S_2 at T_1^* is given by

$$S_2 = \frac{a_i}{3} \left[\frac{\beta}{2b} \right]^{1/3} = \frac{a_i T_1^*}{3} \quad (10)$$

Thus the value of S at T_1^* is given by

$$[S]_{max} = \left[\frac{2}{3} a_r + \frac{a_i}{3} \right] T_1^* \quad (11)$$

[c.f. eqns. (9b) & (10)]

At low temperature where residual resistivity dominates over the ideal resistivity, the Wiedmenn – Frenz law is valid ¹⁰ and

$$\beta = \frac{\rho_r}{L_n}; L_n \text{ is the normal value of Lorentz number.}$$

Further $\rho_{4.2} \approx \rho_r$.

If we write

$$\rho_1 = \frac{\rho_{300}}{2530}; \rho_2 = \frac{\rho_{300}}{2785} \text{ and } \rho_3 = \frac{\rho_{300}}{3270} \quad (11a)$$

Where ρ_1, ρ_2 and ρ_3 are the values of ρ_r corresponding to the values of RR= 2530, 2785 and 3270 respectively, then

$$[\rho_1]^{1/3}; [\rho_2]^{1/3}; [\rho_3]^{1/3} = [\beta_1]^{1/3}; [\beta_2]^{1/3}; [\beta_3]^{1/3} \quad (12)$$

From eqn. (8)

$$(\beta_1):(\beta_2):(\beta_3)^{1/3} = 6.056:5.423:5.07$$

$$=1.089:1.07:1 \quad (13)$$

From eqn. (11a)

$$(\rho_1)^{1/3} : (\rho_2)^{1/3} : (\rho_3)^{1/3} = 1.089:1.055:1 \quad (14)$$

Where, $T_1^* = 6.056, 5.423$ and 5.07 are the temperature at which peaks in curves corresponding to $RR = 2530, 2785$ and 3270 occur. There is a close agreement in ratios in r. h. s. of equations (13), (14). These results confirm that eqn. (8) is valid. A small deviation in ratio of r.h.s. in eqns. (13) & (14) is expected due to small deviation¹⁰ from Wiedmann – Franz law.

We calculate the values of a_r from eqn. (11) using values of $T_1^* = 6.056, 5.423$ and 5.07 K and $a_i = \frac{S_e}{T}$ together with $(S)_{\max} = 46.3, 37.4$, and 30.0 nV K^{-1} , from Table- 1.

These values of a_r are shown in Table- 3. The table –3 shows that, a_r is the function of the values of RR and its value decreases as the value of RR increases, ie, the value of a_r increases with increasing amount of residual resistivity. It is reported¹ that value of RR decreases as the amount of twisting of the sample of Ag increases. It means that the residual resistivity increases with increasing amount of twisting of the sample. After a certain value of twisting, the value of residual resistivity (β) increases so much that eqn. (6b) becomes applicable and S becomes linear function of temperature. Variation of a_r with twisting is already reported in the literature¹¹. As the twisting is increased a_r becomes larger and it becomes more and more dominant over a_i (4.5 nV K^{-2} for Ag) and $\frac{a_i b T^4}{\beta}$ becomes less and less significant.

CONCLUSIONS

On the basis of above results it is concluded that residual resistivity is the major cause of various characteristics of Thermopowers of samples of silver, revealed by experiments¹⁻⁵.

Table 1: Calculated Values of Se, Sg and S from Eqns. (1) & (1a)

T	Se(nVK ⁻¹)	Sg(nVK ⁻¹)	S(nVK ⁻¹)=(Se+Sg)	S(nVK ⁻¹)
6.056	26.98	140.33	167.31	46.3
5.423	24.16	100.76	124.92	37.4
5.07	22.59	82.34	104.93	30.0

Table 2 : Calculated Values of α from Eqn. (2)

S	(S-Se) nVK ⁻¹	α	RR
6.056	19.32	6.1377	2530
5.423	13.24	0.1314	2785
5.07	7.40	.090	3270

Table 3: Calculated Values of S_i at T_1^* and a_r , Values of T_1^* and Peak Values of Thermopowers of Three Samples of Ag

T_1^* (K)	$\frac{1}{3} a_i T_1^*$ (nVK ⁻¹)	S_{\max} (nVK ⁻¹)	a_r (nVK ⁻¹)	RR
6.056	8.963	46.3	9.248	2530
5.423	8.026	37.4	8.125	2785

5.07	7.504	30.0	6.660	3270
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